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<u>Team A</u> - Dr. F. H. Lutze, Dr. H. F. VanLandingham, Mr. T. J. Hertz, and Mr. G. J. Tauke in cooperation with Dr. J. D. Bird and Dr. R. C. Montgomery of the Theoretical Mechanics Branch of the Flight Dynamics and Control Division at NASA Langley.

— Research Objectives: To investigate the use of an on board digital computer as a flight controller for the purposes of stability and flying quality augmentation.

— Results: In order to have a test bed in which to evaluate the control algorithms developed, it is necessary to maintain and improve the EBF-STOL simulation on the EAI690 system hybrid computer located at NASA - Langley. One of the aspects of the simulation which causes subtle problems is the representation of the aerodynamics of the aircraft. This is done on the digital portion of the computer, formerly by a table look-up scheme using a triangular grid to represent the two variable (α, C_T) dependent aerodynamic coefficients (C_m, C_L, C_D) with flap setting as a parameter. Such a representation has several drawbacks. A system identification scheme can oscillate between two of the triangular grids giving significantly different estimates of the variable slopes leading to "chattering" in the estimate. Furthermore, such a representation precludes the use of flap setting as a controller since intermediate flap settings were not permitted.

In order to alleviate these problems and to add flexibility to the simulation a new scheme for representing the aerodynamic coefficient was adopted. It is a three dimensional curve fit of the aerodynamic coefficients to the three variables α, C_T, and δ_f. Such a curve fit provides for smooth derivatives and allows intermediate values of flap setting. The scheme was originally developed for a two variable curve fit and then extended to include the flap setting. This scheme has been checked out and is operating. It appears that the curve fit slightly destabilizes the aircraft from that represented by the table look-up scheme.

Mr. Hertz is investigating a control algorithm based on the scheme proposed by Narendra and Tripathi.(1) It consists of an identification scheme which determines the elements of the system matrix and the control matrix. Once these are determined the appropriate feedback and cross control gains can be determined which yield the "best" handling qualities. The scheme developed for continuous systems is being extended to discrete systems. Several parameters are free to be selected. A search is being made which will select those which give the best control system. Although the continuous system is made stable by selecting these parameters to satisfy a Liapunov criterion, the discrete system has exhibited some instabilities. Further investigation into this problem is being carried out. The method has been applied to a second order system but not to the EBF-STOL.

Mr. Tauke has completed a survey of over 50 articles relating to adaptive control. Various advantages and disadvantages have been listed and discussed. A gain scheduling scheme was developed and tested for a second order system but was found too cumbersome for the EBF-STOL vehicle since the dynamics varied through such large ranges. A second order system was used to test the model reference scheme using Liapunov's theory as given by Porter and Tatnall(2) and was found to work. A scheme to modify this method for digital control of a system whose parameters could not be changed directly was developed and programmed on the Continuous System Modeling Package (CSMP) on the IBM 370 computer. Current tests are being made on the CSMP using a third order system. Upon success, the DC-9 model for the EBF-STOL aircraft will be evaluated.

(1) Narendra, K. S. and Tripathi, S. S., "Identification and Optimization of Aircraft Dynamics," Journal of Aircraft, Vol. 10, No. 4, April, 1973, pp. 193-199.

(2) Porter, B. and Tatnall, M. L., "Performance Characteristics of Multivariable Model-Reference Adaptive Systems Synthesized by Liapunov's Direct Method", International Journal of Control, Vol. 10, No. 3, 1969, pp. 241-257.

—Interaction: Dr. VanLandingham, Dr. Lutze, Mr. Hertz and Mr. Tauke each spent 5 weeks at the Langley Research Center during the first few months covered by this project. At least one trip per quarter was made during the academic year to utilize the hybrid computer. The advantages of the curve fit procedure were discussed at length and a similar technique was developed by Langley personnel for their simulation of the F-8 aircraft.

Team B - Dr. J. W. Schmidt, Mr. R. R. Crockett, Mr. H. L. Cook (Dr. D. M. Miller replaced Dr. Schmidt in June, 1974, and Mr. Gary Schmitt will replace Mr. Cook in September, 1974) in cooperation with Dr. T. M. Walsh of the Flight Instrumentation Division at NASA Langley.

—Research Objectives: (1) To investigate the problem of delay at high density air terminals resulting from the inability of these terminals to efficiently handle the peak demands placed upon them, and (2) to investigate the optimal design of a "hub" airport terminal system with explicit consideration of the multiple objectives involved.

Research Results: To address objective (1), a simulation model was developed of the operations of a nation-wide network of airport terminals. This model was used to test the effectiveness of alternative aircraft scheduling strategies in reducing delay.

After analyzing the results obtained in the simulation by means of a statistical analysis of variance, it was found that a uniform scheduling algorithm, one in which each departing aircraft would be assigned a unique time of departure, displayed the greatest reduction in departure delay. However, since this method would require a complete alteration in present scheduling procedures, a tagging algorithm, one in which each aircraft would absorb delay on the ground at the departure terminal, was suggested as being the most effective because of the conservation of fuel by the aircraft on the ground and because of the fact that no changes would be needed in the present scheduling procedure.

To address objective (2), a model was developed to represent the decision problem of determining the best levels of several decision variables (such as which general aviation airports to modernize and the degree of modernization, and sequencing strategy for arriving and departing aircraft) in terms of a set of multiple objectives. These objectives include minimizing delay time, maximizing safety, and maximizing the acceptance rate of the hub. A simulation model of a hub system is also being developed to test the impact of changes in the decision problems in terms of these multiple objectives.

The Washington hub has been chosen as the system to be modeled. This system consists of one major airport, eight general aviation airports and their surrounding airspaces. Data has been collected and a fast-time FORTRAN simulation is being completed to capture the salient features and random variations associated with arrival, departure and internal flights of the current hub system. In this fashion such system interactions as overlapping terminal areas can be captured. In addition, the flexibility of the simulation can be extended to include such items as controller pilot interaction, controller error, EAS environment, alternative flight routes, and other important considerations.

The input required for the simulation consist of aircraft operations data, hub system component locations (VORTAC's, vector airway intersections, airport runways, final approach paths, etc.), arrival and departure parameters for each element airport, flight routes and flight conflict procedures.

This simulation model is currently being designed and tested. The majority of the necessary data for an analysis of the decision problem as it applies to the Washington, D.C., area has been gathered.

— Publications: An M.S. thesis was completed by Mr. Crockett in May, 1974. The abstract of this thesis follows:

Abstract of the Thesis

At the present time, millions of dollars are being lost by major airlines each year because of the inability of high density air terminals to efficiently service all of the demands placed upon them during peak periods of demand. Up to the present time, studies involving congestion have been aimed primarily at the implementation of computerized

techniques to aid the air traffic controller during peak demand periods. By scheduling aircraft in a given system in a different manner, delay, caused by congestion, could possibly be reduced at high density terminals even more than it has been reduced by the results obtained from previous studies.

The approach taken in this study involves testing different heuristic scheduling algorithms, based on what has been done previously, to determine what extent total system delay can be reduced. The method of approach which was followed was based on a simulator which models aircraft movement between N major terminals. For each scheduling algorithm developed, hourly statistics related to the number of aircraft demanding service, average departure delay, and average arrival delay were calculated along with total system delay times for arriving and departing aircraft. The results obtained from these algorithms were analyzed and compared with the scheduling algorithm which resulted in a reduction in delay being examined in greater detail to determine whether or not such a schedule would actually be feasible and worthwhile.

— Interactions: Dr. J. W. Schmidt made five trips related to the project. Accompanied by Mr. R. R. Crockett, he traveled to the offices of American Airlines, Trans-World Airlines, and Eastern Airlines for the purpose of gathering delay data; to NASA - Langley for coordination purposes; and to the Atlanta air traffic control tower to gather information. Mr. H. L. Cook made two trips to the Federal Aviation Administration for research purposes and spent four days recording data at the Washington National Airport IFR-room. On July 9, Dr. Miller, Mr. H. L. Cook, Mr. G. A. Schmitt and Mr. R. R. Crockett traveled to NASA - Langley to discuss progress to date, familiarize new team members and to obtain suggestions for future research topics.

Team B (continued) - Dr. Jason C. Yu and Mr. Richard D. Kerr in cooperation with Dr. T. M. Walsh of the Flight Instrumentation Division at NASA - Langley.

Research Objectives: During the period from July 1971 to August 1972, preliminary investigations were made to apply the dynamic programming methodology to the determination of the optimal planning of one-stage and multi-stage runway construction schemes. The solution technique was designed to assist the airport planner in establishing the least of cost series and timing of runway configuration replacement in order that the runway capacity will be increased significantly and economically.

The overriding emphasis which guided the research conducted during this year (September 1973 - August 1974) was on bringing the planning model into a highly useful form. This research task of testing, packaging and application is just as critical a step in finalizing a workable planning tool as is the preliminary definition of the problem and selection of solution technique.

In order to accomplish this goal of developing the economic model into a practical planning tool, three areas of research were identified as specific work objectives for this year, as follows:

1. A re-evaluation of the overall study
2. Refinement of the existing analysis program
3. Application of the solution technique to a real-world example

Research Results: Based on the final form of the runway configuration expansion program, and the results of analysis conducted on Washington National Airport and Dulles International Airport, the following conclusions were drawn:

1. Use of sequential configuration alternatives and dynamic programming solution techniques is more efficient in computer execution than the use of nonstructured alternatives and branch-and-bound techniques. The restrictions which this choice places on application of the program are very few, especially in the range of actual cases.
2. The data requirements of the economic analysis are not unreasonable for a long-range planning effort. The data items are ones which should rightfully be considered in a comprehensive plan, yet they are currently difficult to obtain.
3. Development of the computer program as a planning aid with built-in comparative analysis and sensitivity analysis has proven much more valuable than a program which only mathematically optimizes.
4. For the case of Washington National Airport, the addition of a dual fourth runway is indicated as desirable at any time between 1964 and 1983, the bounds of the planning period examined. Addition of high-speed exits along was shown to be uneconomical in terms of reducing delay.
5. For Dulles International Airport, the analysis results indicate that two, rather than the current three, runways are capable of efficiency accommodating projected demands through 1983. This is

true even though no additional land cost was involved for adding the third runway.

6. Preliminary investigations of the combined airport costs reveal potentially sizable savings through control of demand split between the two Washington, D.C. airports. These cost reductions, aiding the aircraft operators and passenger, would occur both with and without addition of the dual runway at National airport.
7. Throughout the case example runs, the ability of the developed solution technique was high, indicating clear-cut distinctions of all alternatives in terms of economic costs.

— Publications: A final full technical report on this research project will be completed by the end of this summer. Also, a research paper will be prepared for publication in a professional journal.

— Research Interactions: In addition to many phone conversations held between this project team and Dr. T. M. Walsh to discuss the development of this research, National Capital Airports, (a division of the FAA), managers of Washington National Airport and Dulles International Airport as well as many other related agencies were consulted for the availability of real-world data for application of the developed solution technique.

Team C - Dr. D. T. Mook, Dr. A. H. Nayfeh, and Mr. O. A. Kandil in cooperation with Dr. E. C. Yates of the Structures Divison at NASA - Langley.

— Research Objectives: To develop procedures for predicting the aerodynamic characteristics of wings which are oscillating about a highly loaded condition in order to aid in the prediction of the flutter and the response to a gust.

— Results: Using the support provided by the Grant, Mr. S. A. Maddox completed the requirements for the M.S. Degree in Engineering Mechanics and graduated. A summary of the work done in completing his M.S. Thesis appeared in the Journal of Aircraft, February 1974, entitled "Extension of a Vortex-Lattice Method to Include the Effects of Leading Edge Separation".

A portion of the work which will be done by Mr. O. A. Kandil in completing his Ph.D. Thesis was presented at the AIAA 7th Fluid and Plasma Dynamics Conference in Palo Alto, CA, in June 1974, as AIAA Paper 74-503 entitled "Nonlinear Prediction of the Aerodynamic Loads on Lifting Surfaces". The paper given in Palo Alto was concerned with incompressible flow only. This restriction was eliminated recently when a modification based on the Prandtl-Glauert transformation was incorporated into the code. An abstract of this work was submitted for presentation at the AIAA for the 13th Aerospace Meeting coming up in 1975.

— Interaction: Members of Team C have had several discussions with Dr. E. C. Yates, Mr. E. Polhamus, and Mr. B. Gloss of NASA - Langley.

Team D - Dr. G. R. Inger, Dr. W. P. Rodden and two students in cooperation with Dr. E. C. Yates of the Structures Division at NASA - Langley.

— Research Objectives: To develop techniques for predicting how viscous boundary layer growth (including separation) modifies potential flow solutions for the aerodynamic loads on oscillating lifting surfaces with trailing edge controls.

— Results:

(a) Potential Flow Study (W. P. Rodden, A. Talug).

Investigation was continued for two-dimensional airfoils based on the combination of the Doublet-Lattice method and the Source-Lattice approach to account for thickness. A computer program for the case of steady flow field prediction using such a discrete numerical model was set up and checked out for the case of a Joukowski airfoil.

It should be pointed out that following W. P. Rodden's resignation from VPI in June 1974, Mr. Talug transferred from the ASE to the ESM Department. Dr. Inger has assumed leadership of the Team D effort dealing with the important viscous flow aspects of the problem; he will act in close collaboration with Team C.

(b) Boundary Layer Study (G. R. Inger, V. Sonnad).

This effort is currently concerned with developing an approximate analytical model of the boundary layer which may be coupled to the aforementioned potential flow solutions to provide an account of the boundary layer displacement and phase-shift effects. Although valuable progress was made in devising an unsteady generalization of this model for application to oscillating airfoils, it was decided to hold this aspect in abeyance for the time being owing to the emphasis on steady flows being pursued in the adjunct potential flow study (a). Accordingly, we focused attention on three major aspects of the steady flow problem which are of controlling importance in evaluating viscous effects near the trailing edge of airfoils and wings: (1) the incorporation of an adequate description of pressure gradient history effects on the highly viscous flow region near the surface; (2) extension of our previous work for laminar flow to the practically - important case of turbulent flow that is likely present near the trailing edges on full-scale aerodynamic surfaces; (3) inclusion of flow separation into our boundary layer with the attendant effects of viscous-inviscid interaction.

Regarding (1), an improved version of the Stratford-Carle "double-deck" boundary layer model for laminar flow has been devised by incorporating a heretofore - neglected account of the inertia terms in the viscous sub-layer region. This significantly extends the applicability of the model, particularly to pressure gradient regions with local maxima or minima as often encountered on airfoils. An M.S. Thesis based on this work is currently under preparation by Mr. V. R. Sonnad of the Aerospace Engineering Department. (2) As a basis for subsequently extending this improved treatment of pressure gradient effects to turbulent flow, a new analytical eddy viscosity equation was devised which (unlike existing law-of-the-wall formulations) is well-behaved in the presence of strong adverse pressure gradients and reversed flow and non-singular at separation. This equation is based on a fundamentally - guided mixing rule that combines wall shear-dominated and pressure gradient - dominated expressions into a composite expression for arbitrary values of a suitable pressure gradient to shear ratio parameter. A report on this is in preparation[1]. (3) Our investigation of interaction and separation has dealt with devising a suitable computational scheme for applying our double-deck boundary layer model in the presence of coupled laminar boundary layer - global subsonic inviscid potential flow interaction. To date, we have succeeded in devising an analytical treatment of this problem supporting the basic computational approach and have presented a paper describing this work[2]. An improved computer program has been written and is undergoing check out. Ultimately, it is intended that this will be combined with the potential flow program being developed in part (a).

— Publications:

(1) Inger, G. R., "On the Law of the Wall for Turbulent Boundary Layers in Strong Adverse Pressure Gradients." VPI and SU AERO-013.

(2) Inger, G. R., "Subsonic Boundary Layer Separation and Reattachment with Viscous - Inviscid Interaction," AIAA Paper 74-582, June 1974.

Team E - Dr. H. F. Brinson, Dr. C. T. Herakovich, Mr. G. D. Renieri, and Mr. M. P. Renieri in cooperation with Dr. John G. Davis, Jr. of the Composite Section, Materials Application Branch of NASA - Langley.

— Research Objective: To survey the commercially available adhesives, choose possible candidates for composite bonding applications, develop specimen configuration and instrumentation, conduct the necessary tests to characterize the viscoelastic-plastic behavior of candidate materials, attempt to establish correlation between experimental results and theoretical models, to develop a finite element computer program capable of analyzing viscoelastic-plastic behavior in composites and to make recommendations for optium design applications.

Results: All testing necessary to ascertain stress-strain/strain-rate and time dependent behavior of two commercially available adhesive materials has been completed. The materials selected for the study were Metlbond 1113 and Metlbond 1113-2. Both materials are made with the same modified epoxy film, but they differ in that 1113 contains a synthetic carrier cloth whereas 1113-2 does not. The materials were tested in bulk form using uniaxial tensile tests at constant strain-rate, tensile creep tests and tensile relaxation tests.

The strain-rate tests were performed using head rates ranging from 0.002 in/min to 2.0 in/min. Stress and strain were recorded continuously to failure; both longitudinal and transverse electrical resistance strain gages were used. Stress-strain results for Metlbond 1113 (with carrier cloth) are shown in Figure 1. The results show that this adhesive exhibits initial linear behavior, followed by nonlinear behavior to failure. The material has a brittle character with little plastic deformation prior to failure. The proportional limit and ultimate stress exhibit significant rate dependence. The ultimate stress results are compared to an emperical equation proposed by Ludwig for metal in Figure 2. As shown in the figure, there is very good correlation for this material. The stress-strain/strain-rate results for Metlbond 1113-2 were similar to the results for the 1113 in that significant rate dependence was observed. However, the 1113-2 adhesive exhibited significant plastic flow (no strain hardening) and correspondingly higher strains prior to failure. This ductility decreased with increasing strain rate. As expected, the material with the carrier cloth (1113) exhibited slightly higher elastic modulus and ultimate stresses.

The more brittle character of the 1113 adhesive is believed to be due to the influence of the carrier cloth on material flow size. Lower ultimate stresses are expected as flow size increases.

Creep test results for 1113 are presented in Figure 3. The results show that the material does exhibit significant time dependence and also that a delayed fracture or creep to failure phenomena is observed. The creep behavior shown in Figure 3 is typical for both materials. Relaxation curves for 1113 are presented in Figure 4. The time dependence is again very evident.

Both materials exhibited a "stress whitening" effect which is shown in Figure 5. This effect is akin to Luder's bond formation in ductile metals and polymers and can be described as a crazing phenomena. The "stress-whitening" demonstrates that load damage in the form of microcracks and local yielding occurs well below the ultimate stress of the material. The phenomena was shown to be both time and rate dependent.

Analytical characterization efforts using emperical polynomials, a Ramberg-Osgood approximation and a modified Bingham mechanical model are now in progress. This experimental work and the analytical characterization are being conducted by Mr. Michael Renieri.

A parallel effort has been the development of a finite element computer program with the capability to analyze elastic, viscoelastic and plastic behavior of anisotropic and/or isotropic composite laminates under generalized plane strain or in bonded joints. A major portion of this effort has been completed in that the program has been developed to the point where it can analyze elastic behavior of angle-ply composite laminates under generalized plane strain. To our knowledge this is the only finite element computer program with such capability. Because of the general formulation which has been used, the program also has the capability to solve problems on the micromechanics level with as many as five different constituent materials in the lamina. Plotter capability is also being incorporated into the program to facilitate interpretation of finite element grids which have been generated by the program and also to facilitate the stress analysis. Figure 6 shows a typical finite element grid which was generated from input of six elements. The program renumbers nodes and elements and then plots the final grid labeling nodes and elements as indicated in the figure.

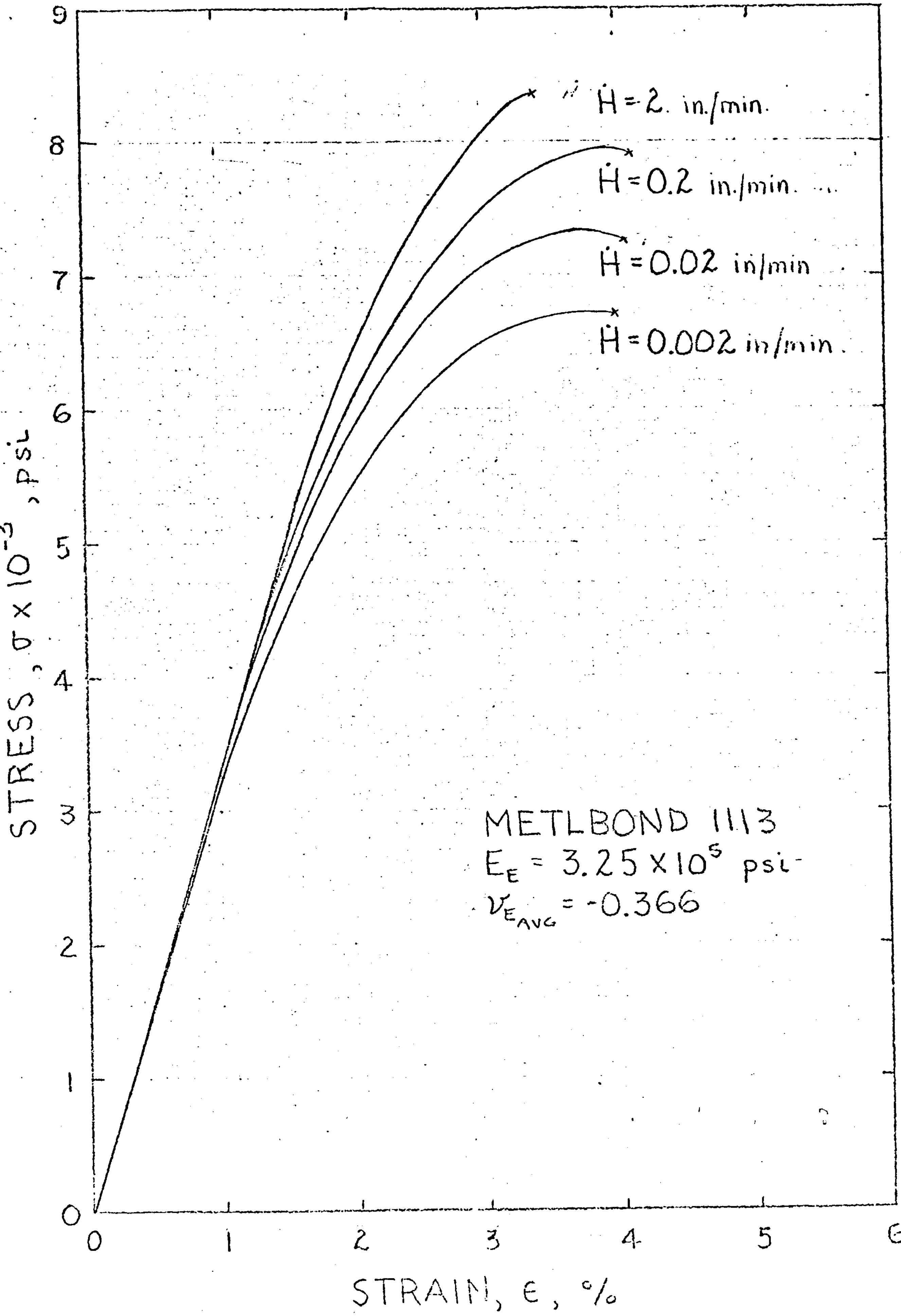
The program works with triangular finite elements and assumes linear variation of displacements in the plane of the element. Displacements in each of three erthoymal directions are allowed at each node point. In addition, a given axial displacement may be specified. The element stiffness matrix has been determined using a strain energy approach.

Typical results obtained from our finite element program and those obtained by Pipes using a finite difference program are presented in Figure 7. The results shown depict the variation of the interlaminar normal stress σy along the interface of a $[0_4/A\ell]_s$ laminate. As indicated in the figure there is very good correlation except near the free edge. Agreement in this region can be improved by using more finite finite elements. The finite element results agree exactly with the finite elements obtained by Foye and Baker. Similar results for an angle-ply laminate have also been obtained.

Current and future work on the computer program will be devoted to the incorporation of thermal effects and nonlinear material and/or viscoelastic behavior. When these features have been incorporated, the program will be used to investigate generalized plane strain problems and bonded joint problems. The finite element work is being conducted by Mr. Gary Renieri.

— Publication: One paper has been accepted for presentation at an ASTM Symposium on Fracture Mechanics of Composites entitled "Rate and Time Dependent Failure of Structural Adhesives."

— Interaction: Mr. M. P. Renieri, and Mr. G. D. Renieri both spent six weeks at NASA - Langley during the summer of 1973. During that time they worked in the Composites Section under the direction of Dr. John Davis. Dr. Herakovich visited with the Composites Section on the first day of their stay. The Composite Section has cured panels of adhesives and then sent them to VPI and SU where specimens were cut from the panels. Strain gages have also been provided by Langley. Dr. Davis visited VPI and SU in early March to discuss the progress of the investigation and Dr. Herakovich visited NASA in May and again in June. In addition, many phone conversations have been held with Dr. Davis.



9
8
7
6
5
4
3
2
1
0
STRESS, σ x 10^-3, psi
Ḣ = 2. in./min.
Ḣ = 0.2 in./min.
Ḣ = 0.02 in/min
Ḣ = 0.002 in/min.
METLBOND 1113
E_E = 3.25 x 10^5 psi
ν_E_AVG = -0.366
0
1
2
3
4
5
6
STRAIN, ε, %

FIGURE 1

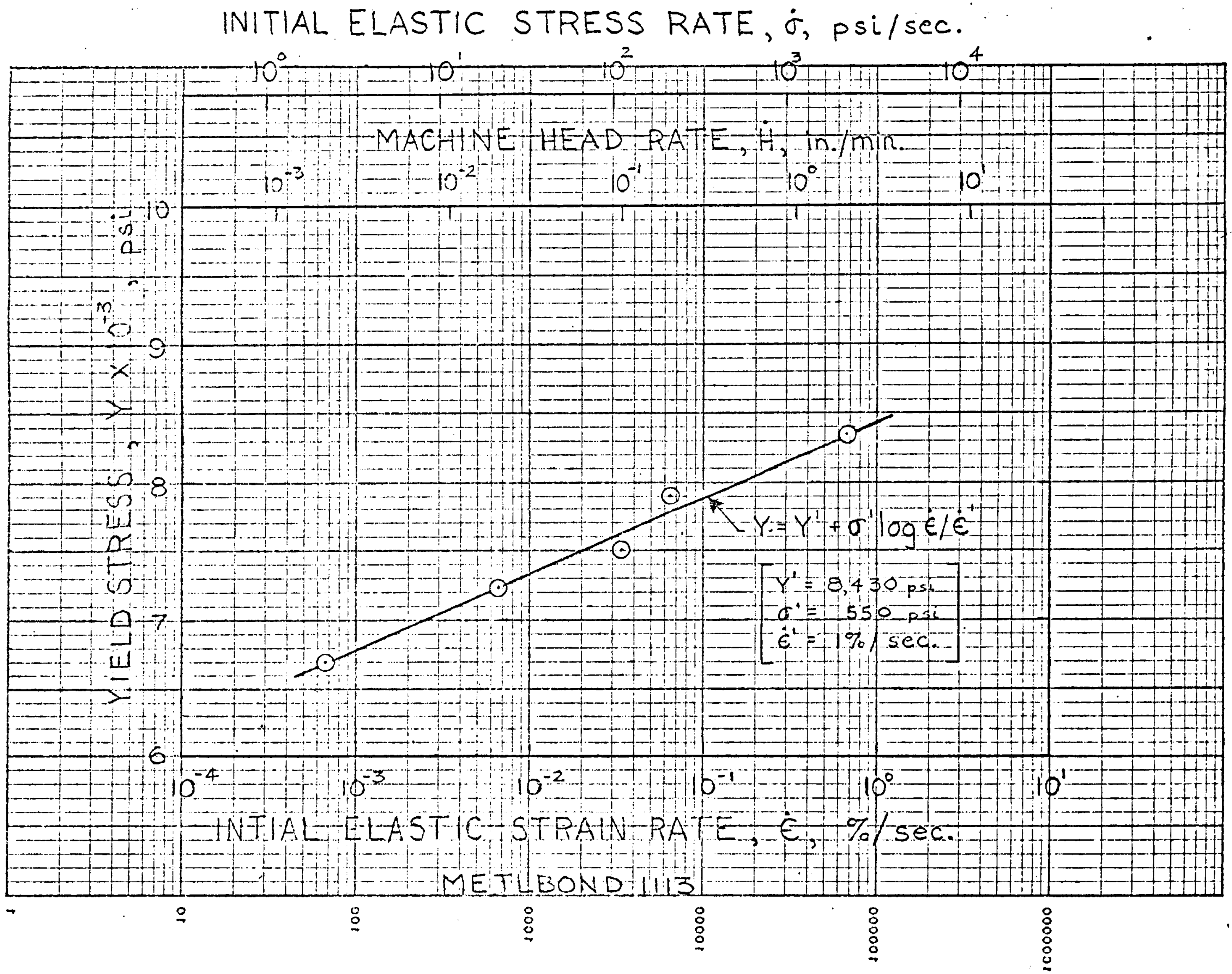
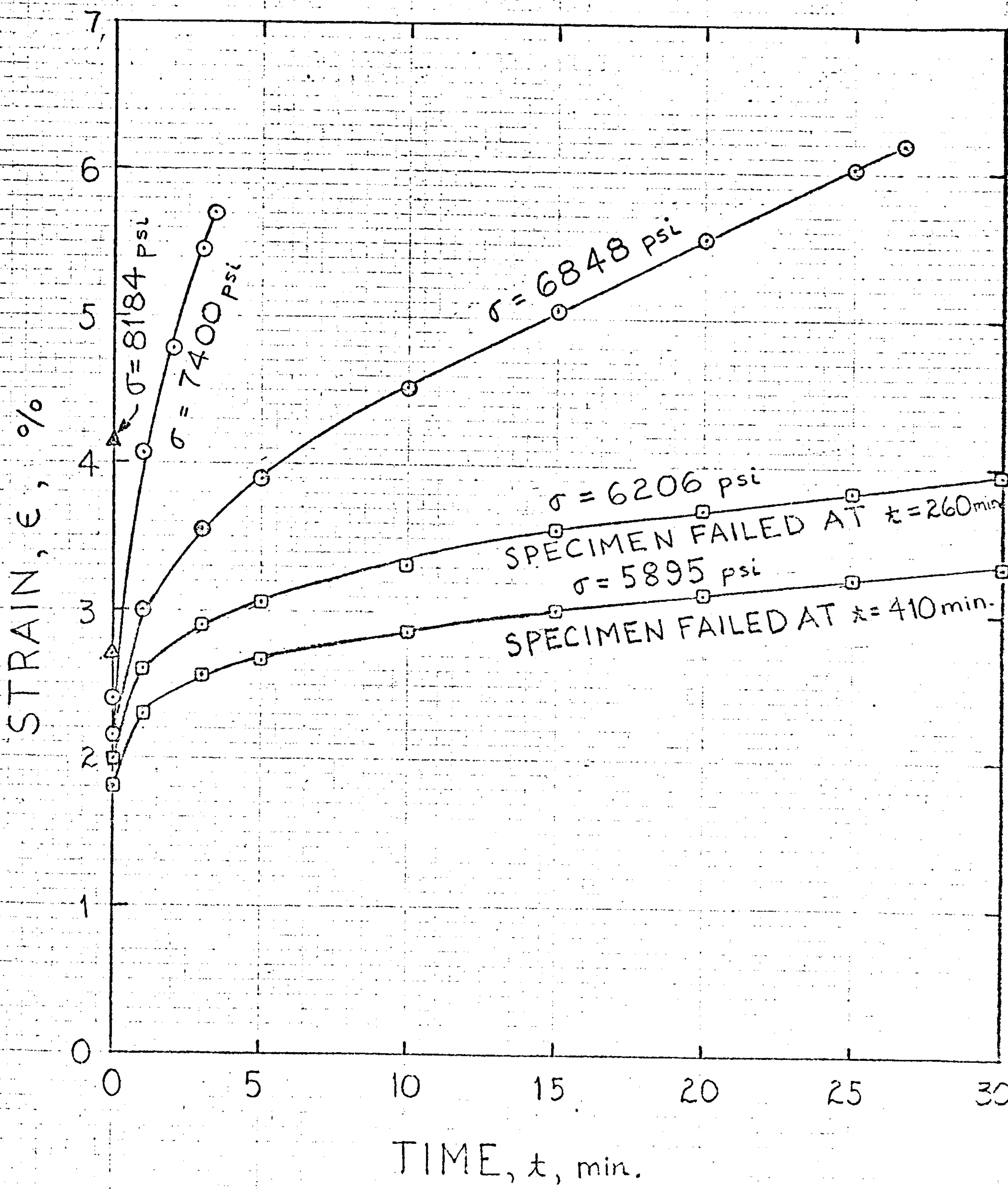
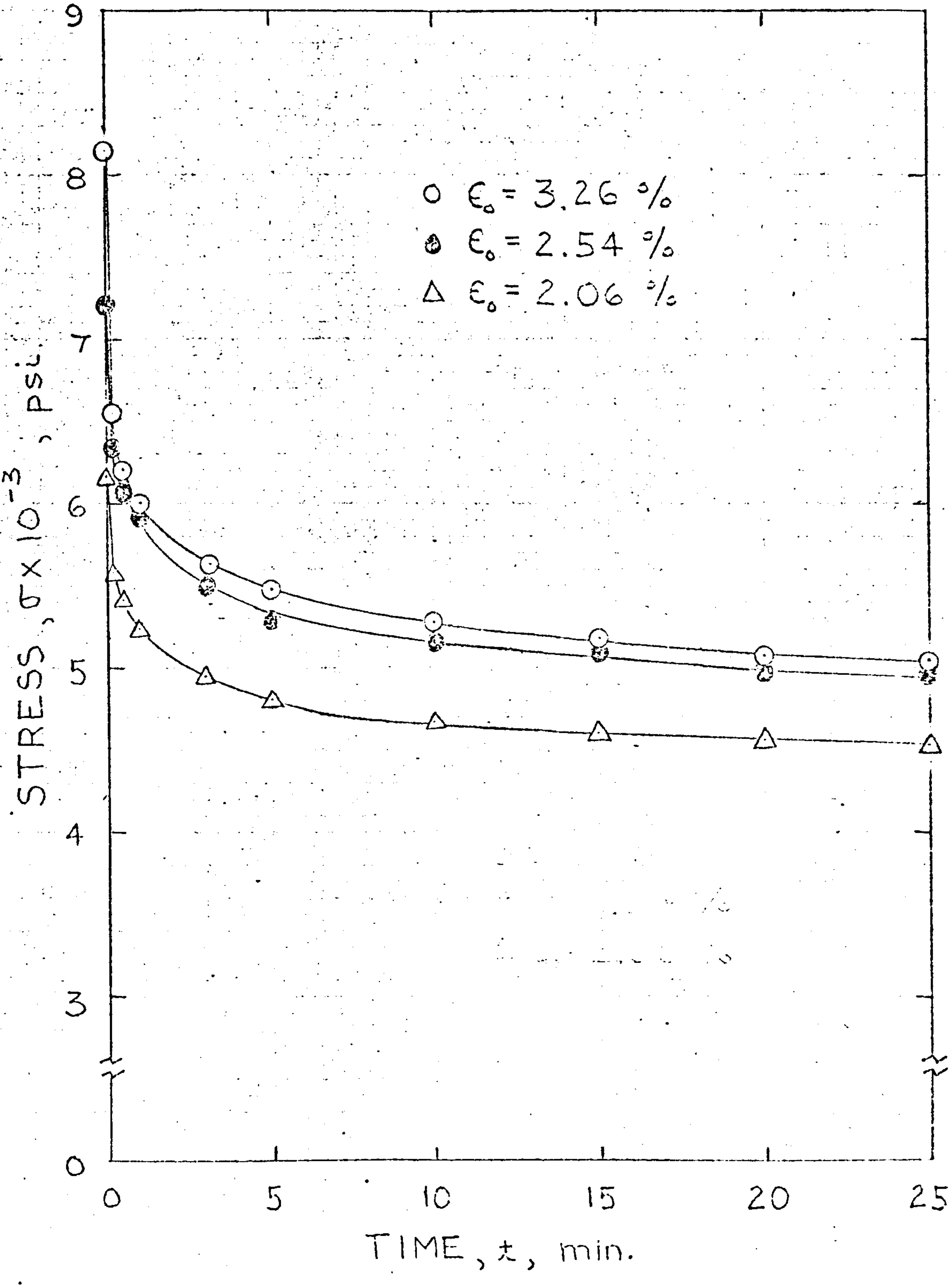

INITIAL ELASTIC STRESS RATE, $\dot{\sigma}$, psi/sec.
10^0 10^1 10^2 10^3 10^4
MACHINE HEAD RATE, $\dot{H}$, in./min.
10^{-3} 10^{-2} 10^{-1} 10^0 10^1
YIELD STRESS, Y X 10^{-3}, psi
10 9 8 7 6
$Y = Y' + \sigma' \log \dot{\epsilon}/\dot{\epsilon}'$
$Y' = 8,430$ psi
$\sigma' = 550$ psi
$\dot{\epsilon}' = 1\%/$sec.
10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^0 10^1
INITIAL ELASTIC STRAIN RATE, $\dot{\epsilon}$, %/sec.
METLBOND 1113
DATE
MODEL

FIGURE 2



CREEP RESPONSE
METLBOND 1113

FIGURE 3



METLBOND 1113

FIGURE 4

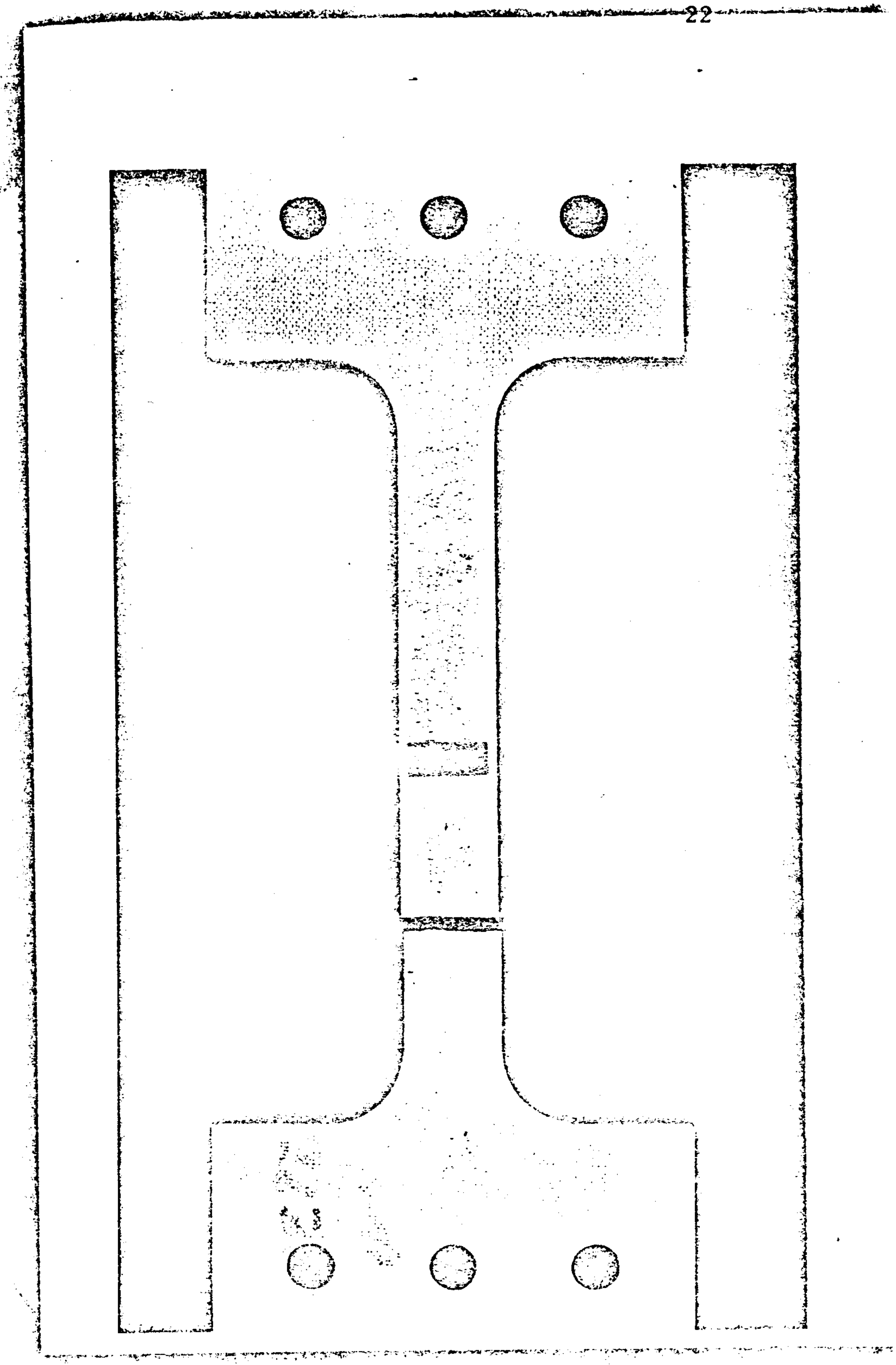


FIGURE 5

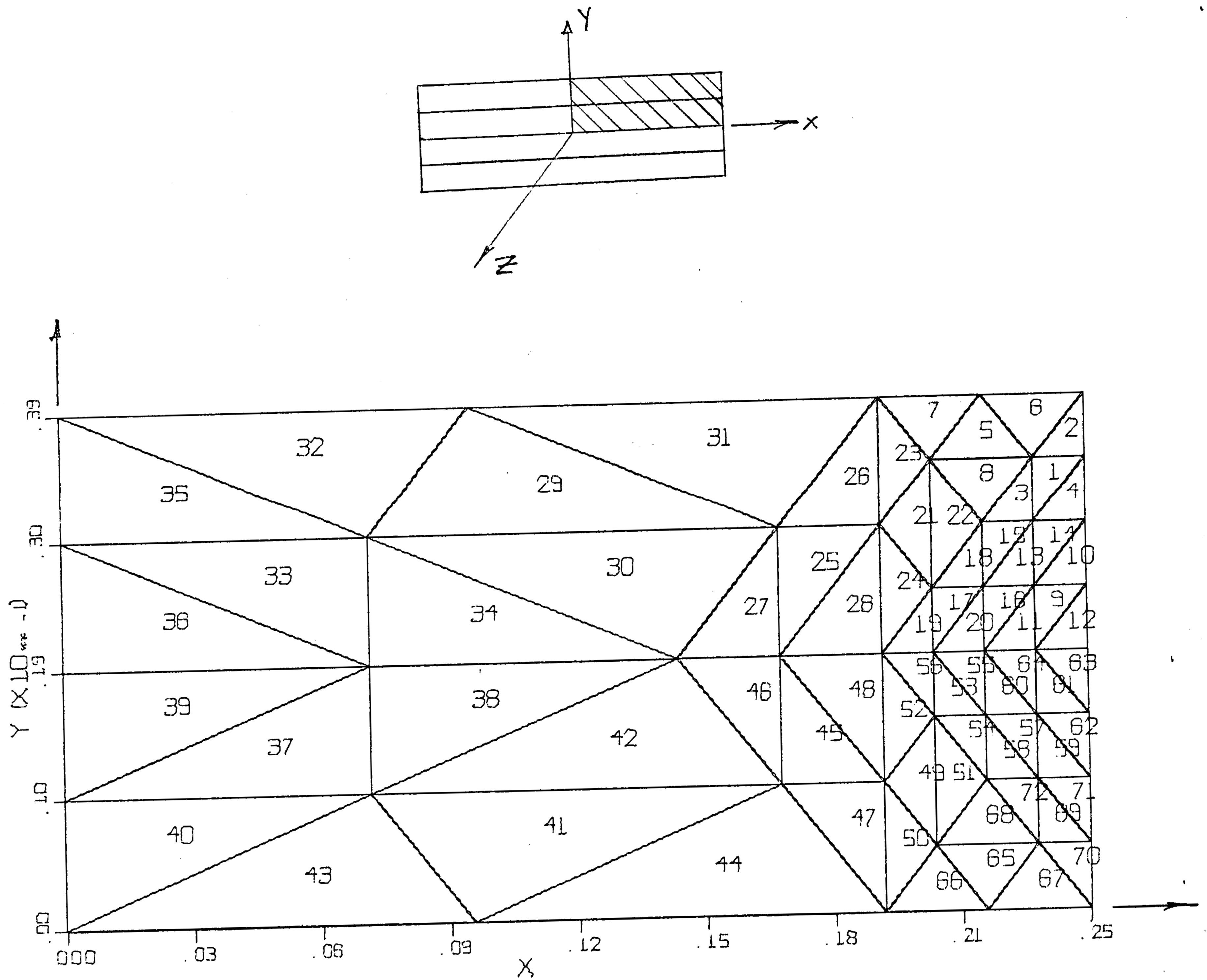


FIGURE 6

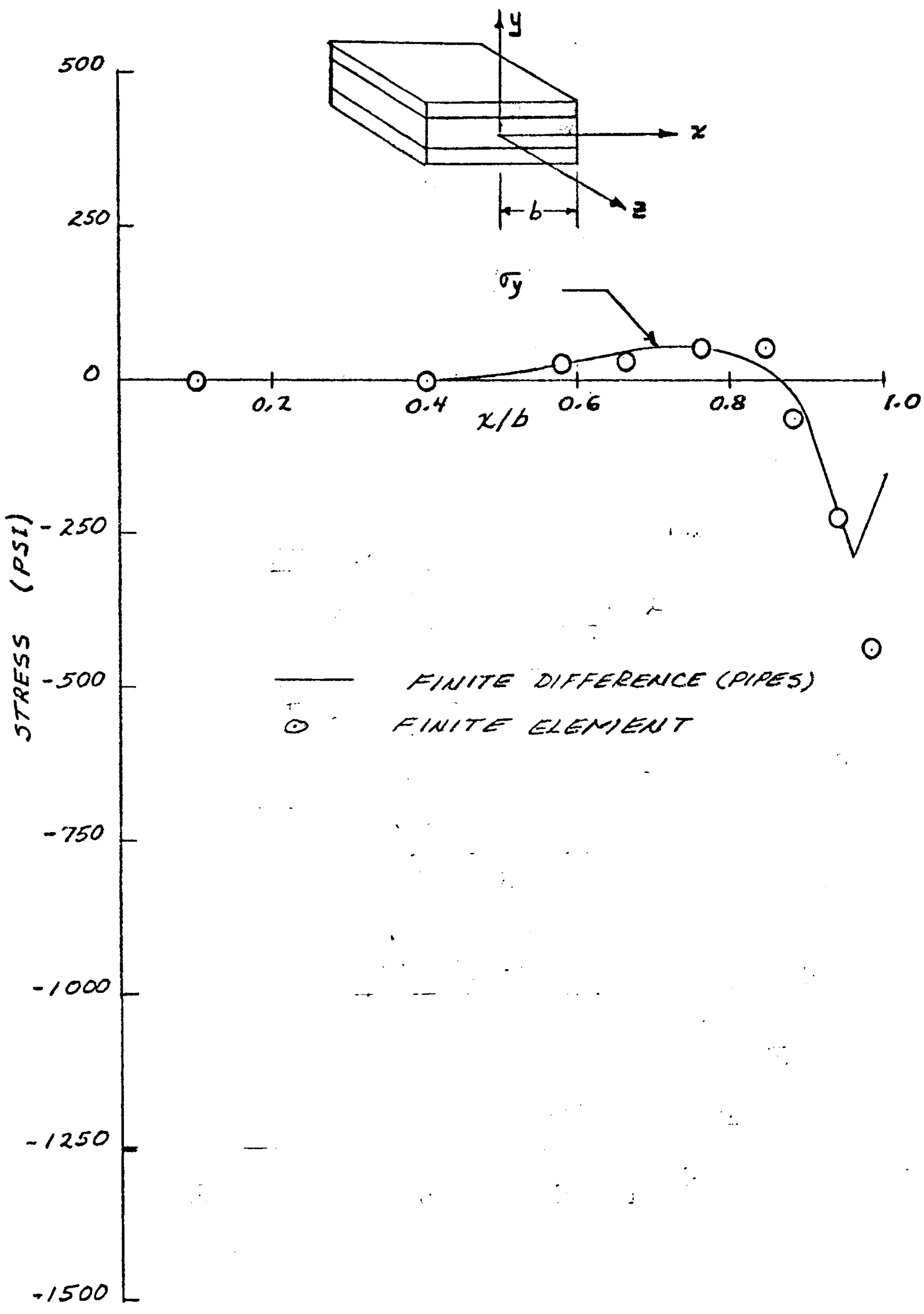

y
x
z
b
500
250
0
-250
-500
-750
-1000
-1250
-1500
STRESS (PSI)
0.2
0.4
0.6
0.8
1.0
x/b
σy
FINITE DIFFERENCE (PIPES)
FINITE ELEMENT

FIGURE 7